Exploring the Impact of Smartphone Addiction in Prospective Memory

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***Abstract*—As smartphones have rapidly emerged as a ubiquitous and indispensable technology, there are increasing indications that user dependence on smartphones and associated behaviors could be considered a form of addiction. Intensive interaction with smartphones has a significant impact on user thought patterns, cognitive focus and memory. Prospective memory is the mechanism which allows us to remember to do something at some future time or to remember some future event. Prospective memory plays an important role in our daily lives, acting as a mental calendar which organizes awareness of future events and thus allows people to plan accordingly. Continued reduced performance of prospective memory may cause us brain degradation. Intensive smartphone use creates long-term distractions, and thus reduces prospective memory use. Using a Smartphone Addiction Inventory questionnaire, followed by dual-task and electroencephalography (EEG) experiments to measure prospective memory performance, we found that some correlation between smartphone addiction and deterioration of prospective memory.**

***Index Terms*—smartphone addiction, prospective memory, electroencephalogram**

I. Introduction

Prospective memory is a cognitive mechanism which allows people to remember the significance of some future event, or to take some action at some future time [1]. Prospective memory can be either time-based or event-based [2]. For example, remembering to attend a meeting at 3:00 pm is time-based prospective memory, while remembering to pass a message to someone when one next sees that person is event-based prospective memory. These cognitive functions are indispensable to daily life, but 50-70% of all memory failures are prospective memory failures [3], and such failures can have serious consequences (e.g., a surgeon forgetting to check remove all surgical implements before closing a wound).

Memory represents an accumulated record of a person's life, including events, feelings and experiences. It is most typically understood as *retrospective memory*, i.e. recall of past events, such as remembering contents of a book one has read. However in daily life, we often need to remember to do something at some future time, such as attending a meeting, or buying milk on the way home from work. This type of memory is called *prospective memory*.

Modern life is fast-paced and it's easy for people to forget things. Previous studies have demonstrated that 50-70% of such daily memory failures are attributed to prospective memory [3], and such lapses can have serious or potentially life-threatening implications. Thus, anything that acts to degrade or compromise prospective memory is a serious issue.

This paper explores the impact of the degree of smartphone addiction on prospective memory performance by using Smartphone Addiction Inventory (SPAI) questionnaires to measure degree of smartphone addiction. Dual-task experiments were carried out to assess impact on prospective memory. During experimental tasks, participant brain activity was monitored using an electroencephalographic (EEG) monitoring device.

II. Literature Review

A. Prospective Memory

Prospective memory is a cognitive mechanism which allows people to remember the significance of some future event, or to take some action at some future time [1]. Prospective memory can be either time-based or event-based [2]. For example, remembering to attend a meeting at 3:00 pm is time-based prospective memory, while remembering to pass a message to someone when one next sees that person is event-based prospective memory. These cognitive functions are indispensable to daily life, but 50-70% of all memory failures are prospective memory failures [3], and such failures can have serious consequences (e.g., a surgeon forgetting to

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check remove all surgical implements before closing a wound).

Ref. [4] Hannon & Daneman that prospective memory consists of five stages: (1) Encoding, in which the person encodes cues (such as 3:00 pm) and intentions (attending a meeting), along with the relationship between cues and intentions. (2) Delay: since prospective memory involves remembering to do something in the future, its encoding is conducted "at present" but the subject of the memory is something to be completed "in future". Thus, there must be a delay period from the completion of the encoding to the occurrence of prospective memory cues. During this delay, the subject typically engages in other ongoing tasks. (3) Cue detection: prospective memory cues must be immediately and accurately detected and understood. Failed cue detection results in one knowing one is supposed to do something, but being unable to remember when. Cue detection in prospective memory is an automatic activation process. In order words, people actively detect prospective memory cues and this process of cue detection is regarded as a component of prospective memory. (4) Intention search: when a prospective memory cue is detected, the subject scans previously encoded intentions from memory and decodes them to determine the associated intentions. Intention search is regarded as a retrospective component in prospective memory. (5) Execution: once the associated intention is identified, the previously planned actions are executed.

B. Impact of Smartphone Addictions on Memory

At the publication meeting of Radiological Society of North America in 2017, researchers from Korean universities used brain imaging technologies to study the brains of 19 teenage boys diagnosed as having Internet or smartphone addictions [5]. Compared to a control group, the addicted subjects were found to have significantly higher ratio of Gamma Aminobutyric Acid (GABA) to glutamate-glutamine (Glx). GABA slows nerve cell operations, reducing cognitive focus and control, and thus elevating anxiety. Some researchers have proposed that excessive smartphone dependency would lead to the development of lazy cognitive habits, substituting rapid and perceptual intuition for more tiring analysis and thinking [6]. Cognitive function is related to prospective memory. In dual-process theory, cognition is divided into two modes: 1) intuitive and heuristic thinking, which is similar to the automatic activation process of prospective memory and 2) analytic thinking, which is related to the strategic monitoring of prospective memory, since people often need to remember future events through thinking and analysis [7]. Cognitive focus is related to strategic monitoring, and thus smartphone addiction may degrade prospective memory performance.

III. EXPERIMENT

Dual-task experiments were conducted to control external variables [2]. Smartphone addiction was classified as high and low, and both event-based and time-based prospective memory tasks were tested.

A. Experimetal Process

(1) Participants: Eight postgraduate students were recruited to participate in the experiments; 5 male and 3 female, ranging from 23-33 years old.

(2) Procedure: Each participant was tested in respect of smartphone addiction measurement and daily prospective memory measurements for about 10 minutes. Then each participant spent about 15 minutes engaged in both time-based and event-based prospective memory tasks with each session separated by a one week interval to prevent participants from becoming too familiar with the tasks, as shown in Fig. 1.

(3) Measures: The Smartphone Addiction Inventory (SPAI) was used to investigate the degree of smartphone addiction [8]. It contained 26 questions with a total score of 104, where a higher score indicates greater addiction. In this paper, participants scoring 69-71 were classified as low addiction, while participants scoring 75-86 were classified as high addiction. A total of eight Prospective and Retrospective Memory Questionnaire (PRMQ) [9] items were used to assess event-based and time-based prospective memory performance, where a higher score indicates worse performance.

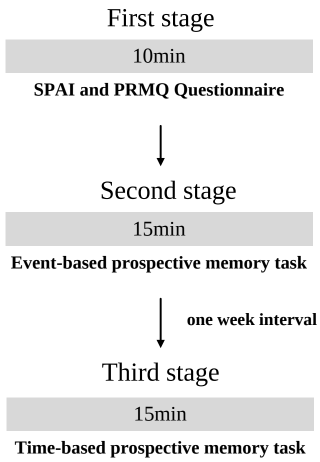

Figure 1. Experimental process.

B. Prospective Memory Task

Prospective memory tasks were designed following previous studies [10], [2], [11].

1) Event-based prospective memory task

One hundred nouns were grouped evenly into ten groups organized by a common theme (e.g., animals, clothing, transportation device, etc.). Two words were then selected at random and this pair was displayed on screen for 1.75 seconds in 54 pt traditional Chinese characters. Subjects pressed the "F" key when the two items belonged to the same theme, and otherwise pressed "J" if the two words were not clearly related, as shown in Fig. 2. In a second event-based prospective memory task, subjects were given a theme (e.g., "aquatic animals") and asked to press the space bar if both words presented on screen belonged to that theme, as shown in Fig. 3. Respondents were quizzed on a total of 520 pairs over 15 minutes.

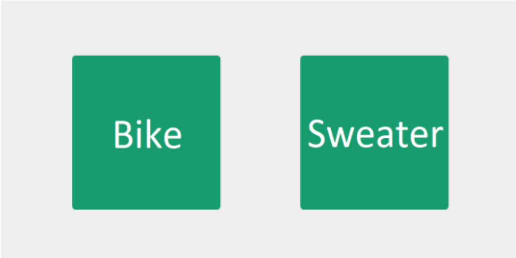

Figure 2. Common theme (animals, clothing, etc.)

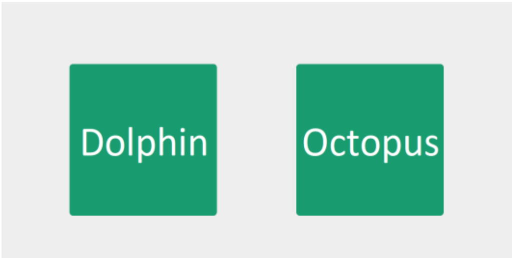

Figure 3. Specific theme (aquatic animals)

2) Time-based prospective memory task

This task is identical to the event-based prospective memory task described above, except that respondents had to reset a hidden clock every three minutes by pressing the "C" key. Respondents could check the clock time by pressing the "Z" key, but the default status of the clock was invisible to the user. Thus, the task required respondents to remain aware of the secondary clock-resetting task while engaged in the primary word matching task.

C. EEG Measurement and Data Processing

During the prospective memory tasks, participants were connected to a Brain Rhythm Inc. BR8 PLUS EEG device (Fig. 4) used to collect brain-wave data from 8 electrode points (Fig. 5) with sampling frequency of 500Hz. The collected brain-wave data were transmitted via Bluetooth to a desktop computer in real-time. A Butterworth Filter (BF) was used to eliminate noise from the physiological signals. Using Fast Fourier Transform (FFT), time-domain signals were converted into frequency-domain signals to capture brain waves of different frequency bands at each electrode point, i.e. δ-wave (0.5~4Hz), θ-wave (4~7Hz), α-wave (8~13Hz), and β-wave (14-30Hz).

Figure 4. BR8 PLUS EEG device

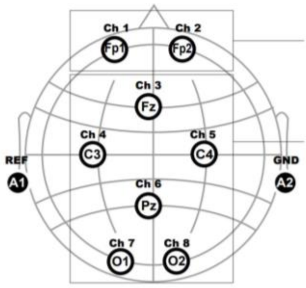

Figure 5. 8 Electrode placement

IV. EXPERIMENTALINDINGS

Independent sample tests were used to assess the impact of smartphone addiction on prospective memory, the performance of which was measured using participant brain-wave data recorded during the event-based prospective memory tasks. ANOVA was used to analyze participant brain-wave data in terms of response error frequency when performing time-based prospective memory tasks.

A. Comparison of High and Low Smartphone Addiction Participants

Table I summarizes the impact of smartphone addiction on prospective memory performance. Average values show the high addiction group exhibited relatively lower prospective memory performance, though the difference is not statically significant. Several participants said they had prospective memory failures in the same day after receiving daily prospective memory experiments, but they did not think prospective memory failures occurred frequently in their life when completing the questionnaire. It was found that participants were not sure of their daily prospective memory performance.

As shown in Table II, the high-addiction groups showed a significantly reduced performance in the event-based prospective memory tasks ($p<0.1$). As shown in Table III, the high-addiction group also showed an average disadvantage in the time-based prospective memory performance, but this difference was not significant, two participants in the high-addiction group had relatively small Response Error Times (RET), because they could check the clock when completing time-based prospective memory tasks. Table IV shows that the average number of time checks was higher in the high-addiction group.

TABLE I. AVERAGE DAILY PROSPECTIVE MEMORY PERFORMANCE

Group	Mean	SD	Mean difference	df	*F*	*p*
High addition	24.500	8.266	-2.750	6	1.058	0.582
Low addition	21.750	4.573				

TABLE II. AVERAGE MEMORY FAILURES OF EVENT-BASED PROSPECTIVE MEMORY

Group	Mean	SD	Mean difference	df	*F*	*p*
High addition	6.000	2.582	-3.500	6	0.750	0.065*
Low addition	2.500	1.732				

TABLE III. AVERAGE RESPONSE ERROR TIMES OF TIME-BASED PROSPECTIVE MEMORY

Group	Mean	SD	Mean difference	df	*F*	*p*
High addition	5.000	4.814	-4.150	6	6.508	0.183
Low addition	0.850	0.640				

TABLE IV. AVERAGE TIME CHECKS OF TIME-BASED PROSPECTIVE MEMORY

Group	Mean	SD	Mean difference	df	*F*	*p*
High addition	43.50	12.503	-10.750	6	0.591	0.190
Low addition	32.75	7.411				

B. Brain Waves Characteristics for Prospective Memory

During event-based prospective memory tasks, brain waves associated with improved prospective memory showed significant reactions at electrode points Fp1, Fp2, Fz (frontal lobe) and C4 (center of parietal lobe), Pz (parietal lobe), and O1 (occipital lobe). These results are consistent with previous findings [12]-[14]. At electrode points Fp1, Fp2, Fz and O1, the δ-wave showed a significant difference which might be due to deep meditation while retrieving prospective memories. At Fp1 and Fp2, the θ-wave showed different reactions because continuous focus was required for prospective memory tasks. At Fp1 and C4, lower α-wave power indicated increased cognitive focus as participants sought to quickly classify task words and identify prospective memory events. β-wave performance varied at the Fz point, indicating that participants were under stress from experiencing prospective memory failure. (Table V)

TABLE V. ANOVA RESULT OF EVENT-BASED PROSPECTIVE MEMORY (REMEMBER/FAILURE)

Feature	Remember		Forget		F	*p*
	Mean	SD	Mean	SD		
Fp1.Delta	6.599	8.650	10.956	6.937	3.136	0.007***
Fp1.Theta	9.053	8.931	12.503	7.503	3.886	0.041**
Fp1.Alpha	4.728	7.371	7.621	5.739	5.395	0.017**
Fp1.Beta	-5.496	4.923	-4.343	4.782	0.167	0.225
Fp2.Delta	7.826	7.830	11.249	5.944	4.508	0.007***
Fp2.Theta	9.614	8.392	12.595	7.161	2.061	0.060*
Fp2.Alpha	5.839	6.471	6.619	5.665	1.336	0.523
Fp2.Beta	-4.834	4.543	-3.958	4.315	0.875	0.315
Fz.Delta	3.567	6.824	5.781	5.986	2.191	0.087*
Fz.Theta	6.631	5.522	8.163	5.218	0.081	0.148
Fz.Alpha	2.967	4.695	3.838	4.228	0.235	0.329
Fz.Beta	-6.723	3.939	-5.402	3.828	0.505	0.083*
C3.Delta	9.147	8.770	8.722	8.824	0.089	0.803
C3.Theta	10.525	8.005	9.730	7.936	0.234	0.607
C3.Alpha	7.623	8.055	6.481	7.532	1.109	0.458
C3.Beta	-0.332	8.040	-2.253	7.140	1.898	0.208
C4.Delta	6.459	7.891	5.544	5.414	5.467	0.434
C4.Theta	8.758	7.348	7.045	6.810	0.069	0.223
C4.Alpha	6.671	7.470	4.272	5.536	5.434	0.042**
C4.Beta	-1.156	8.389	-3.227	6.463	7.729	0.126
Pz.Delta	7.900	7.520	5.120	8.491	0.279	0.065*
Pz.Theta	8.319	4.680	7.388	5.822	1.506	0.331
Pz.Alpha	5.556	4.159	4.674	4.395	0.048	0.280
Pz.Beta	-1.843	4.198	-3.148	4.651	0.019	0.118
O1.Delta	11.600	4.958	9.029	6.477	3.899	0.013**
O1.Theta	10.104	3.794	9.114	4.926	2.373	0.208
O1.Alpha	7.145	3.176	6.208	4.342	1.308	0.162
O1.Beta	0.255	3.329	-0.753	4.332	0.938	0.145
O2.Delta	7.120	6.477	8.055	6.426	0.000	0.455
O2.Theta	7.858	5.467	7.198	5.122	1.152	0.528
O2.Alpha	5.052	4.572	5.319	4.346	1.478	0.761
O2.Beta	-2.234	4.327	-1.230	3.735	2.004	0.219

Note: p<0.1*;p<0.05**;p<0.01***

During the time-based prospective memory tasks, brain waves with low, medium and high Response Error Times (RET) showed significant reactions at Fp2, Fz (frontal lobe), C3 (center of parietal lobe), and Pz (parietal lobe); while the δ-wave showed significant variation at Fp2 and Fz; and the θ-wave showed different reactions at Fp2, Fz and C3 because participants needed to simultaneously perform their assigned tasks while monitoring time, thus adding to cognitive loading. The α-wave showed variation at C3 as participants sought to differentiate word categories under time pressure. The β-wave showed significant variation at Fz, C3 and Pz, possibly due to increased mental stress from performing prospective memory tasks while monitoring time. (Table VI)

TABLE VI. ANOVA RESULT OF TIME-BASED PROSPECTIVE MEMORY (LOW, MEDIUM AND HIGH RESPONSE ERROR TIMES)

Feature	Low (RET)		Medium(RET)		High (RET)		F	*p*
	Mean	SD	Mean	SD	Mean	SD		
Fp1.Delta	6.848	7.146	11.873	4.404	12.875	3.173	2.457	0.100
Fp1.Theta	11.046	7.492	14.998	5.883	18.670	3.963	2.179	0.127
Fp1.Alpha	6.248	6.896	9.020	5.453	10.464	4.907	0.938	0.400
Fp1.Beta	-7.035	4.233	-4.870	4.186	-3.537	1.933	1.553	0.225
Fp2.Delta	5.279	8.865	10.928	6.432	13.915	2.484	2.477	0.098*
Fp2.Theta	10.080	8.015	15.630	6.918	18.426	3.089	2.751	0.077*
Fp2.Alpha	6.343	6.322	9.199	7.157	9.840	4.365	0.867	0.428
Fp2.Beta	-6.286	4.609	-4.861	5.254	-3.131	2.958	0.801	0.456
Fz.Delta	3.494	7.912	5.600	5.556	15.443	13.385	3.101	0.057*
Fz.Theta	8.398	7.673	10.092	4.316	19.988	15.339	2.979	0.063*
Fz.Alpha	5.124	6.692	4.861	2.254	11.943	14.552	1.386	0.263
Fz.Beta	-6.035	5.533	-6.260	2.085	2.001	12.570	2.728	0.078*
C3.Delta	12.321	9.236	4.421	6.188	8.906	9.521	2.337	0.111
C3.Theta	15.669	6.521	9.251	7.244	12.099	7.400	2.781	0.075*
C3.Alpha	11.734	7.585	4.607	7.031	13.085	7.999	2.727	0.079*
C3.Beta	4.153	9.203	-4.813	6.947	4.079	12.793	2.791	0.074*
C4.Delta	9.074	7.403	4.779	4.991	9.891	2.693	1.182	0.318
C4.Theta	12.122	6.163	8.038	5.647	13.181	5.912	1.412	0.257
C4.Alpha	8.401	7.667	4.181	5.889	11.537	7.045	1.324	0.278
C4.Beta	-1.323	8.834	-5.657	4.761	2.224	7.722	1.172	0.321
Pz.Delta	1.608	7.201	3.858	2.703	4.316	2.157	0.513	0.603
Pz.Theta	5.153	6.588	7.868	3.534	6.004	1.121	0.583	0.563
Pz.Alpha	2.157	3.882	3.308	2.928	4.808	0.514	0.906	0.413
Pz.Beta	-7.213	3.527	-4.649	2.849	-3.663	2.672	2.768	0.076*
O1.Delta	1.154	5.710	4.540	7.501	6.126	3.622	1.655	0.205
O1.Theta	5.806	3.317	7.264	1.525	7.151	2.410	0.818	0.449
O1.Alpha	4.988	3.082	4.405	1.260	4.366	1.354	0.170	0.844
O1.Beta	-1.559	2.832	-2.986	2.609	-1.052	2.118	0.867	0.429
O2.Delta	7.244	8.926	6.806	2.315	13.804	7.294	0.933	0.402
O2.Theta	9.560	8.719	6.131	4.548	12.825	6.980	0.833	0.443
O2.Alpha	6.284	6.460	6.320	3.900	7.300	6.974	0.037	0.963
O2.Beta	-1.106	3.992	-2.426	3.150	-1.688	4.317	0.338	0.716

Note: p<0.1*;p<0.05**;p<0.01***

V. CONCLUSION

A high degree of smartphone addiction is found to have a significant and negative impact on event-based prospective memory performance. While no significant impact was found in time-based prospective memory performance and this degradation of prospective memory may be caused by other factors, such as personality attributes or poor sense of time, and these factors should be investigated in future work. Results from this study indicate that brain-wave characteristic values and brain areas associated with event-based and time-based prospective memory performance could be used as an objective basis for future evaluations of prospective memory.

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